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HYDRAULIC TEST LOOP FOR NONFLAMMABLE HYDRAULIC FLUID

**INTERIM REPORT
TFLRF No. 299**

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13. ABSTRACT (Maximum 200 words) A test stand was constructed to evaluate the suitability of the non-flammable hydraulic fluid, chlorotrifluoroethylene (CTFE) for Army applications. The test loop consists primarily of stainless steel and elastomers suited to the CTFE fluid. A 150-hp electric motor, capable of speeds from 0 to 1800 rpm drives a 40 gpm, 4500 psi, variable displacement hydraulic pump. The test apparatus features a "bootstrap" reservoir that utilizes the output pressure of the pump to pressurize the inlet to the pump to the required 80 psi. The reservoir also serves to close the system to the atmosphere, a requirement to prevent exposure of the hydrophilic fluid to atmospheric water. Durability of the current pump on CTFE fluid was limited. However, the rig can be retrofitted with CTFE compatible pumps if required. The rig is completely instrumented to measure shaft horsepower delivered to the pump, fluid flows and pressures and temperatures. A personal computer is used for data acquisition and control of the drive motor and system hydraulics. Conceivably any hydraulic component i.e. valves, actuators, or pumps could be performance and autonomously endurance tested on this test stand.				
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EXECUTIVE SUMMARY

Problem: Non-flammable hydraulic fluid (NFH) is a highly desirable advancement for inclusion in the next generation of military combat vehicles. However, due to its' marked fluid dynamic property and material compatibility differences from conventional fluids a specially designed test rig is required to evaluate vehicle system components.

Objective: The objective of this program was to develop a hydraulic test rig, which was compatible with the non-flammable fluid Mil-H-53119, CTFE based non-flammable hydraulic fluid for testing Army vehicle hydraulic system components.

Importance of Project: The availability of this equipment will promote the use of NFH in future and possibly present Army vehicles thus improving the survivability of the crew and vehicles.

Technical Approach: A review of current and future Army hydraulic system needs was made to size the capacity and power requirements for the test rig. A literature review of past research of NFH fluid was made to identify the problem areas. A design was then drafted and approved by Army (TFLRF) personnel then constructed and tested to validate its' performance.

Accomplishments: A 150-hp, 40 gallon per minute, 4500 psi, hydraulic test rig, compatible with NFH was constructed and tested. A 40-hour endurance test was conducted autonomously under computer control. The endurance testing revealed that the pump was not suitable for the low viscosity fluid.

Military Impact: The use of the test rig will promote the use of NFH fluid in current and future Army vehicles and thus serve to improve survivability of both solders' and vehicles.

FOREWORD/ACKNOWLEDGMENTS

The author wishes to acknowledge the engineering cooperation of Mr. Sam Fujii, Application Engineering Manager, at Denison Hydraulics, for providing the second test pump, the engineering evaluation of that pump following the testing, and Messrs. Joe Stieber and Glen Wendel of the Engine and Vehicle Research Division for providing the design and component selection of the hydraulic system. Special recognition is made of Mr. Greg Phillips for his special skills and persevering which ultimately made this project successful.

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I. INTRODUCTION

To enable the Army to conduct in-house hydraulic fluid and component research, a test apparatus has been constructed at the U.S. Army TARDEC Fuels and Lubricant Research Facility located at Southwest Research Institute. It has been designed to be compatible with all current and proposed hydraulic fluids.

To attain maximum flexibility as a hydraulic test stand maximum use of stainless steel, Teflon and Viton-G materials were used. These materials are compatible with the non-flammable hydraulic fluid (NFH), chlorotrifluoroethylene (CTFE), as well as all conventional and proposed fluids including the biodegradable candidates.

The following design goals were established for the test stand to enable the testing of the largest hydraulic components in the Army inventory:

Total fluid flow	40 gpm
Maximum pressure	4500 psi
Maximum fluid temperature	180°F

These goals have been met; a pump performance curve obtained while operating on CTFE is presented in Figure 1, which represents the maximum pressures and flow rates that the current pump and associated hydraulic components can attain.

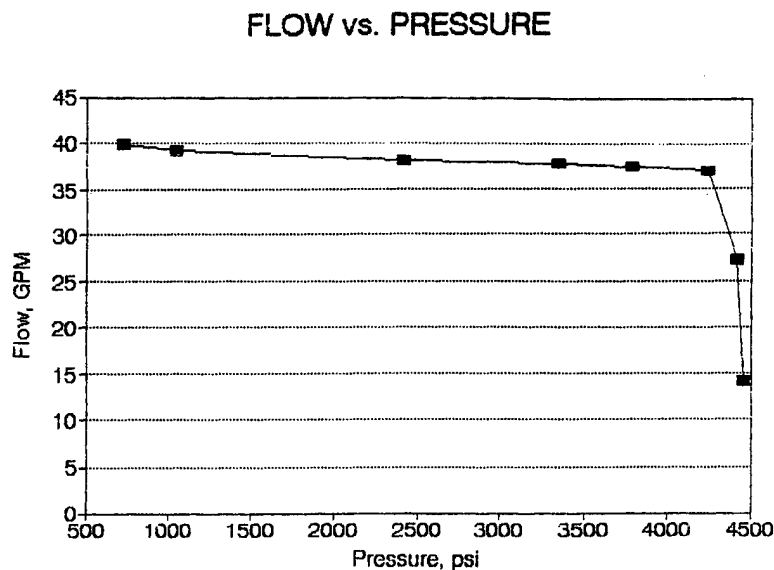


Figure 1. Pump Performance Curve

II. DESCRIPTION OF FACILITY

An overall photograph of the test rig is shown in Figure 2. The rig consists of four sub-components; the drive motor's power inverter, the drive motor and pump bedplate, the hydraulic stand, and the computer console.

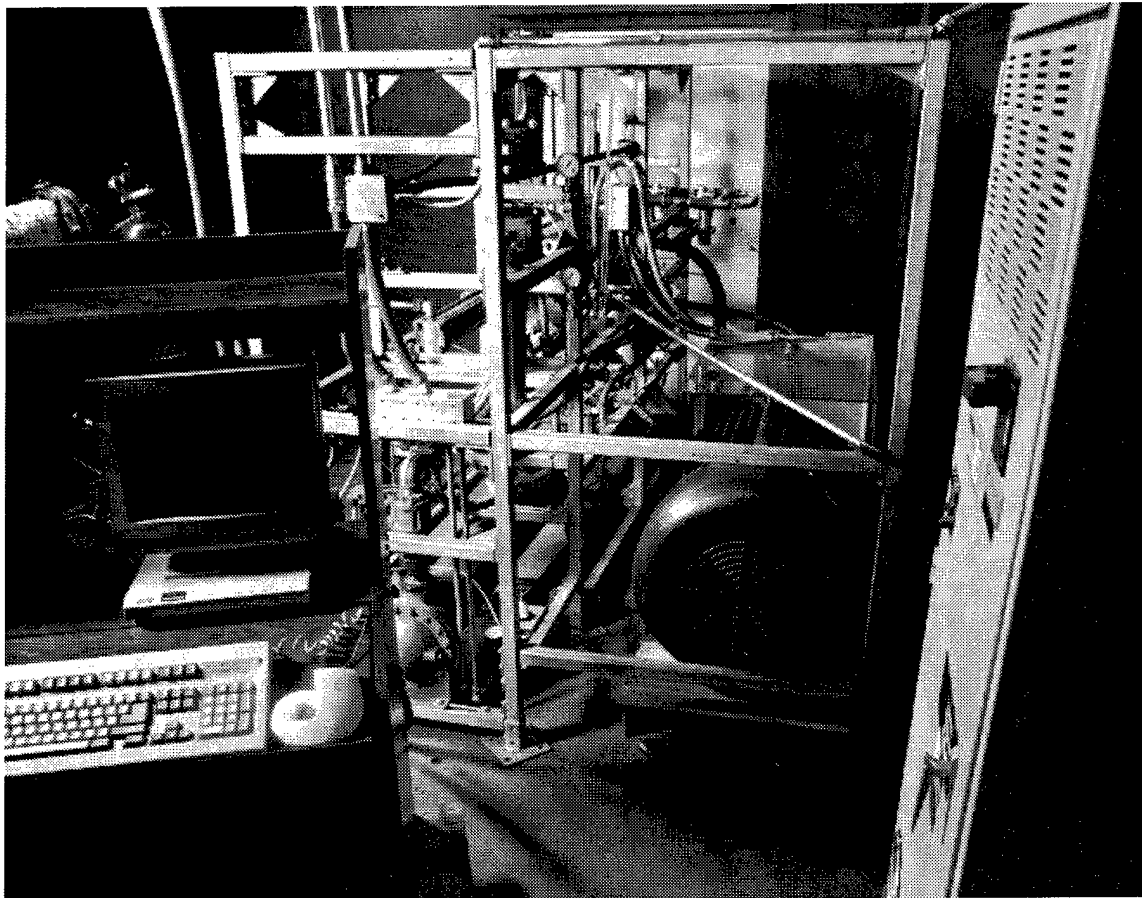


Figure 2. Hydraulic Test Rig

The drive motor power inverter is a large wall mounted NEMA 1 enclosure, which is connected to the 460 AC mains. The inverter supplies variable frequency power to the 150-hp (11.2 kW) electric motor for the equivalent of 0 to 1800 rpm. The speed control can be from the front panel or from the computer.

The drive motor and pump base plate is pictured in Figure 3. It consists of the 150-hp electric motor, an adjustable torque limiting slip coupling, and a strain gage type electronic torque meter.

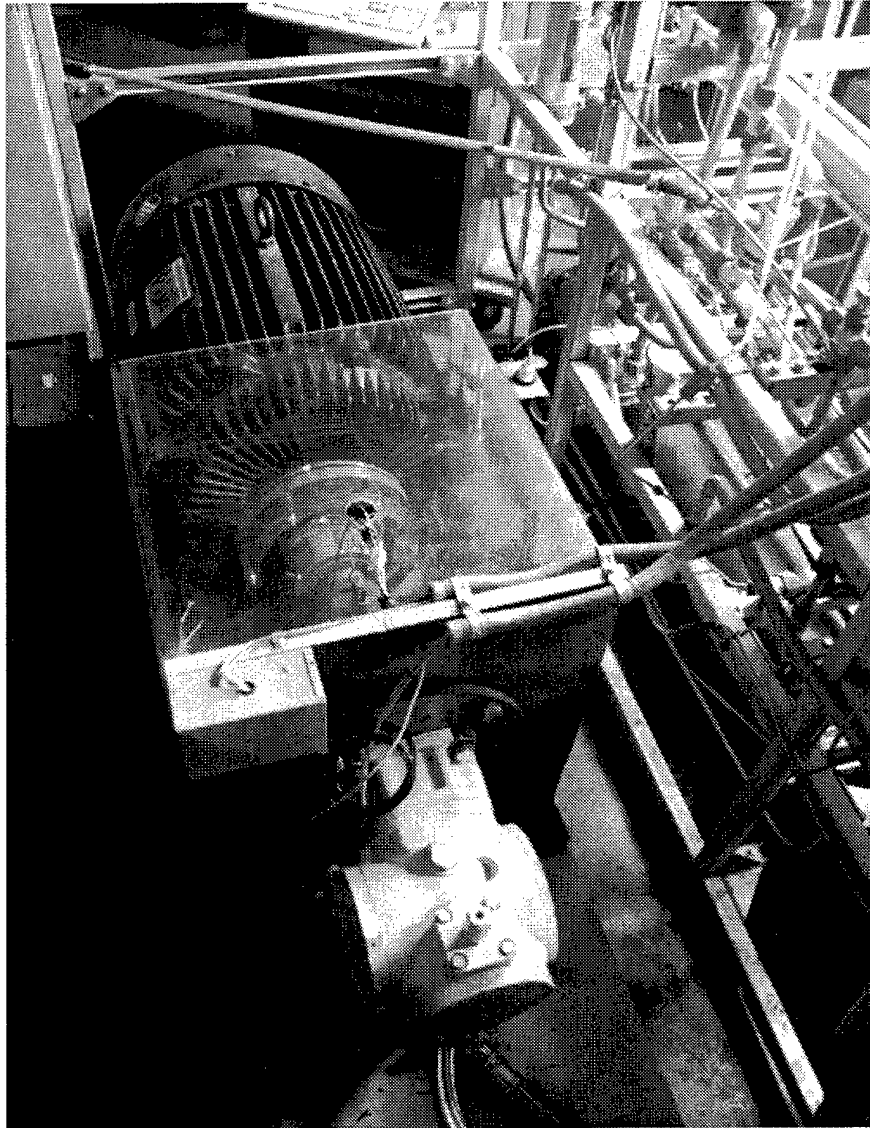


Figure 3. Drive Motor and Pump Base Plate

The torque meter output and actual shaft speed as detected by a 60-tooth wheel and magnetic pick-up are inputs to the data acquisition system. The pump is mounted to the bedplate via the interchangeable faceplate, which will permit different pumps to be readily fitted to the rig. Flexible hose is used to connect the pump to the hydraulic test stand.

The hydraulic test stand, pictured in Figure 4, is constructed using the "Unistrut" system of square steel members and bolted joints. This system was chosen for maximum flexibility enabling rapid changes in the rig to meet a particular test requirement. The outside perimeter of the rig is

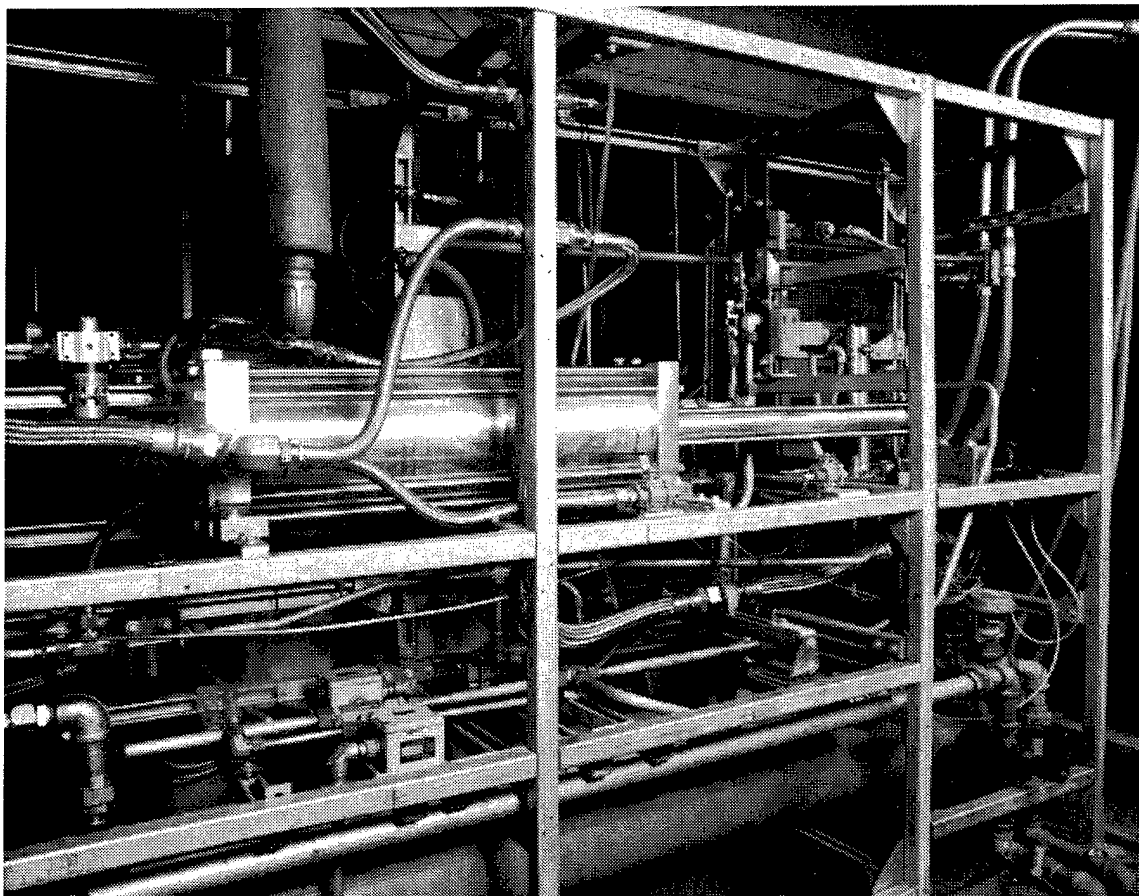


Figure 4. Hydraulic Test Stand

covered in Lexan clear plastic material, which provides protection to the operator in case of a high-pressure leak of fluid.

The basic test rig flow schematic is given in Figure 5. The majority of the hard plumbing consists of stainless tubing terminated with Parker "O"-ring face seals. Pipe threaded joints were avoided wherever possible. All pipe-threaded joints were silver soldered to provide excellent protection from leakage.

Referring to the flow schematic, starting at the pump, a Denison load compensated, variable displacement type pump draws fluid from the bootstrap reservoir, which holds 10 gallons of fluid at 80 psi. The pump discharge is directed to a turbine type flowmeter, a 10 micron filter with integral bypass, and then the device under test (DUT) or in this case for a pump test, a Rexroth proportional relief valve or proportional flow control valve. The pressure drop across either valve can be varied (manually or by the computer) and the flowrates recorded to develop the typical

4,500-PSI CTFE LABORATORY **HYD SYS DEMONSTRATOR**

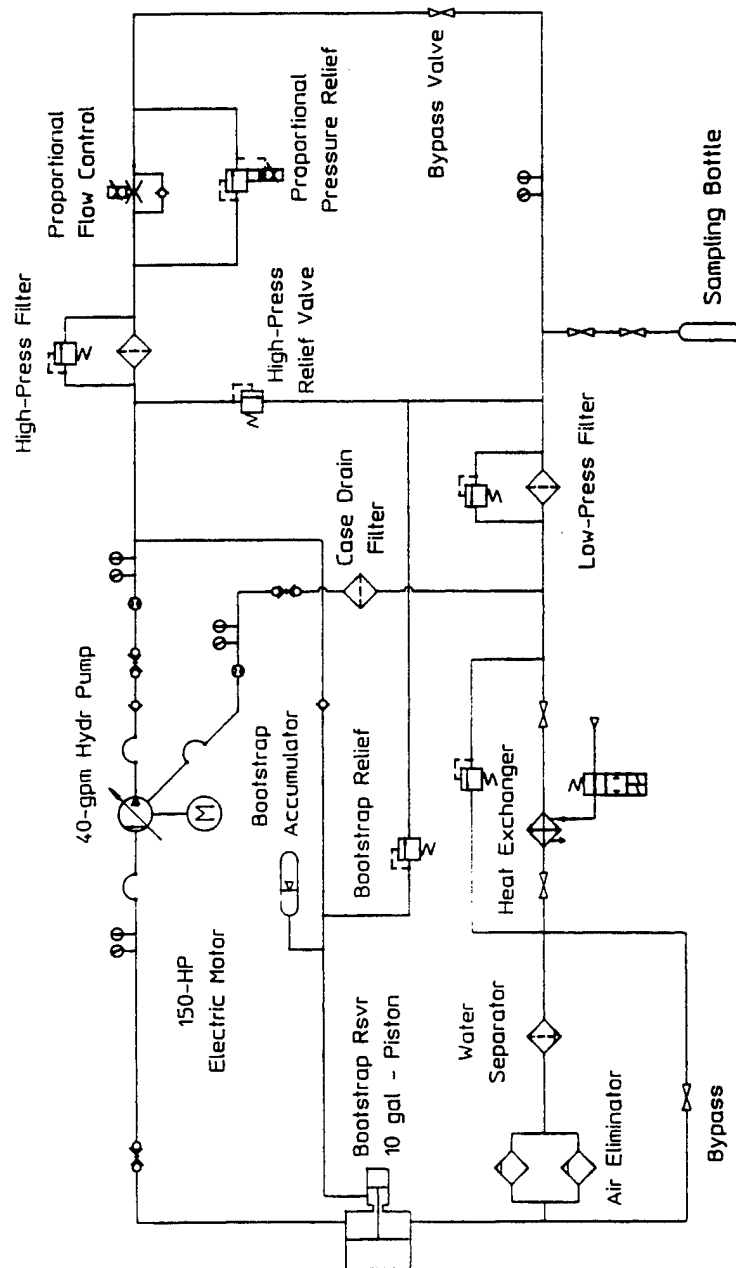


Figure 5. Basic Test Rig Flow Schematic

pump performance curve as shown in Figure 1. On the low pressure side of the Rexroth valve the fluid is again filtered and then passed through a heat exchanger, water and air eliminators before returning to the reservoir. A heater loop for the fluid is also provided to meet the test requirements if needed.

The inlet pressure has been specified by the manufacture to prevent cavitation at the pump inlet. A circuit is provided from the high-pressure side to the bootstrap reservoir to maintain the pump inlet pressure at 80 psi. The bootstrap reservoir consists of two pistons and cylinders sharing a common piston shaft. The area ratio between the pistons is 40 to 1. Thus by setting the pressure regulator to 3200 psi (80 psi times 40) the pump inlet side of the reservoir is pressurized to the required level. The accumulator serves to hold the pressure in the system during shutdowns.

Two stainless 0.5 l sampling bottles are installed in the flow loop which allow fluid samples to be drawn while the rig is running.

A personal computer based data acquisition and control system was developed for the hydraulic test rig. Using a 486-33 processor, 16 Mb memory, and a 120 Mb disk, the system is able to record 32 channels of data at 2000 Hz and output 8 channels of analog voltage or current loop control signals. A list of computer input and output variables is given in Table 1.

Table 1. Computer Input and Output Variables

Input Variables	Output Variables
Shaft speed	Rexroth proportional control valve
Shaft torque	Rexroth flow control valve
Pump discharge pressure	I/P used to control a pneumatic valve regulating the cooling water flow to the heat exchanger
Pump discharge temperature	Pump speed
Case drain pressure	
Case drain temperature	
Pump inlet pressure	
Pump inlet temperature	
Valve low-pressure side pressure	
Valve low-pressure side temperature	

A safety system is implemented in the software, which will stop the motor if the fluid pressure or temperature exceeds preset limits. This system allows the rig to be operated unattended during extended endurance testing resulting in considerable cost savings.

III. SUMMARY

A hydraulic test rig was constructed which met the project goals. The test rig was successfully operated to obtain pump performance curves and ran unattended for 41 hours. However, during the endurance testing it was found that the pump is not well suited to CTFE. The test was repeated using a pump supplied by the manufacturer with the same result. The pump would clog the discharge filter with brass slivers. The only possible source of this debris is the kingsbury pads of the pump. Disassembly of the first pump at TFLRF confirmed the high wear and source of the debris. The second test pump was disassembled and inspected at the manufacturer's facility with TFLRF personnel present to observe. The manufacturer's representative confirmed the high wear at the kingsbury pads.

IV. RECOMMENDATION

It is recommended that this apparatus be considered for the evaluation of new fluids and hydraulic components. Smaller pumps (i.e. 20 gal/min) have been identified which have proven compatibility with CTFE if that is the test fluid. It is conceivable that two of these pumps could be used to obtain the maximum flow capacity of the test rig if that was required. Funding limitations prevented the use of these pumps in the test rig. The current 40-gallon per minute pump would be suitable for many other fluids.

APPENDIX A
SUMMARY OF THE TEST STAND DEVELOPMENT

SUMMARY OF THE TEST STAND DEVELOPMENT

The development of this apparatus required the working through many problems. Below is a summary of the highlights of that activity. Some of the problems were of the typical nature of such projects i.e. unreliable transducer readings, or unstable control loops and omitted from this summary, and some problems were due to particularities of the CTFE fluid itself, but ultimately, as solutions to those problems were found, it became apparent that the pump itself was not suitable for use with CTFE and the testing was discontinued.

- Pipe joints sealed using pipe joint compound, were found to leak soon after filling the rig with CTFE
- 2 wraps of Teflon tape on the pipe threads still resulted in most pipe joints leaking
- silver soldered all the pipe thread joints, no further leaks
- developed a method for filling the bootstrap reservoir and charging the accumulator and corrected an omission of a hydraulic line in the pump load compensator circuit
- Low-pressure side relief valve dumps approximately 5 gallons overboard as pump speed approached maximum
- added a second air eliminator to the low pressure side to reduce the back pressure
- as the pressures and flowrates were increased near the design limits high vibration levels lead to the failure of gages and pressure transducers that were mounted on the hydraulic lines. These items were remounted in rubber on the Unistrut frame and connected to the lines using flexible hose and pressure snubbers
- Several major changes are made; the high vibration levels and flow instability are due to the proportional flow control valve so a proportional pressure relief valve is installed in parallel to the original valve with the necessary switching valves, the heat exchanger is replumbed directing the hydraulic fluid to the shell and cooling water to the tubes
- Smooth pump curves are now obtained but the flowrate is shown to decrease as the pressure is increased, however, the shaft power into the pump is observed to increase with the pressure increases as expected, thus making the flowmeter readings suspect

- relocating the discharge flowmeter to isolate it from the pulsating flow yields proper readings
- obtained a pump performance curve with a maximum pressure of 4000 psi
- Dennison rep visits site and recommends a replacement pressure compensator circuit to correct the low output pressure
- New pressure compensator circuit raises output to 4500 psi
- Started endurance test at maximum flow of 40 gpm and pressure of 4500 psi
- Terminated test at 41 hours when the maximum output pressure fell to 2500 psi
- Tear down of pump and test rig revealed wear of the brass kingsbury pads and brass flakes and slivers in all the filters
- Pump was reassembled and installed on the pump stand
- Repeated cleaning of the filters did not improve the performance
- Pump was replaced with a unit from the manufacture and the system drained and flushed with filtered fluid several times
- new pump produced brass flakes (considered normal in a new pump) and brass slivers (abnormal wear indicated) at low pressure and low flowrates
- Repeated cleaning of the filters did not improve the performance

APPENDIX B
PUMP ENDURANCE TEST RESULTS

PUMP ENDURANCE TEST RESULTS

The test pump was a Denison Model P6W -R5B-C10-00-M2. This is a variable displacement, axial piston type pump, 4500-psi, 6 cubic inch displacement per rev at maximum stroke. It would deliver 40 gpm at 1540 rpm. The system was filled with 20 gallons of MIL-H-53119 NFH CTFE fluid. The fluid temperature was controlled at 175°F during the testing and the pump was set at 4500 psi and 40 gpm. The endurance test was to run for 200 hours with the intent of detecting wear by detecting the level of metals in the fluid.

The proposed 200-hour test ended at 41 hours due to the inability of the pump to develop pressure. This represented a major failure of the pump. Figures 1 and 2 depict the pump flowrate versus pressure and pump efficiency before the endurance test and Figures 3 and 4 are the same curves obtained after 41 hours of operation at the test conditions stated above.

There is a marked difference in the ability of the pump to develop pressure and flow following the accumulation of the test hours. The inability to develop flow-work adversely affected the efficiency curves.

A high amount of brass flakes and slivers were collected in the pump discharge filter, which is visible in the photograph, Figure B-5. Appendix C includes photographs of the pump components after the test.

Table 1 summarizes the laboratory testing of the fluid. No deterioration of the fluid was detected by the laboratory analysis. The x-ray did not detect the brass in the fluid because the particles were too large to remain suspended in the fluid.

FLOW vs. PRESSURE 1-26-94

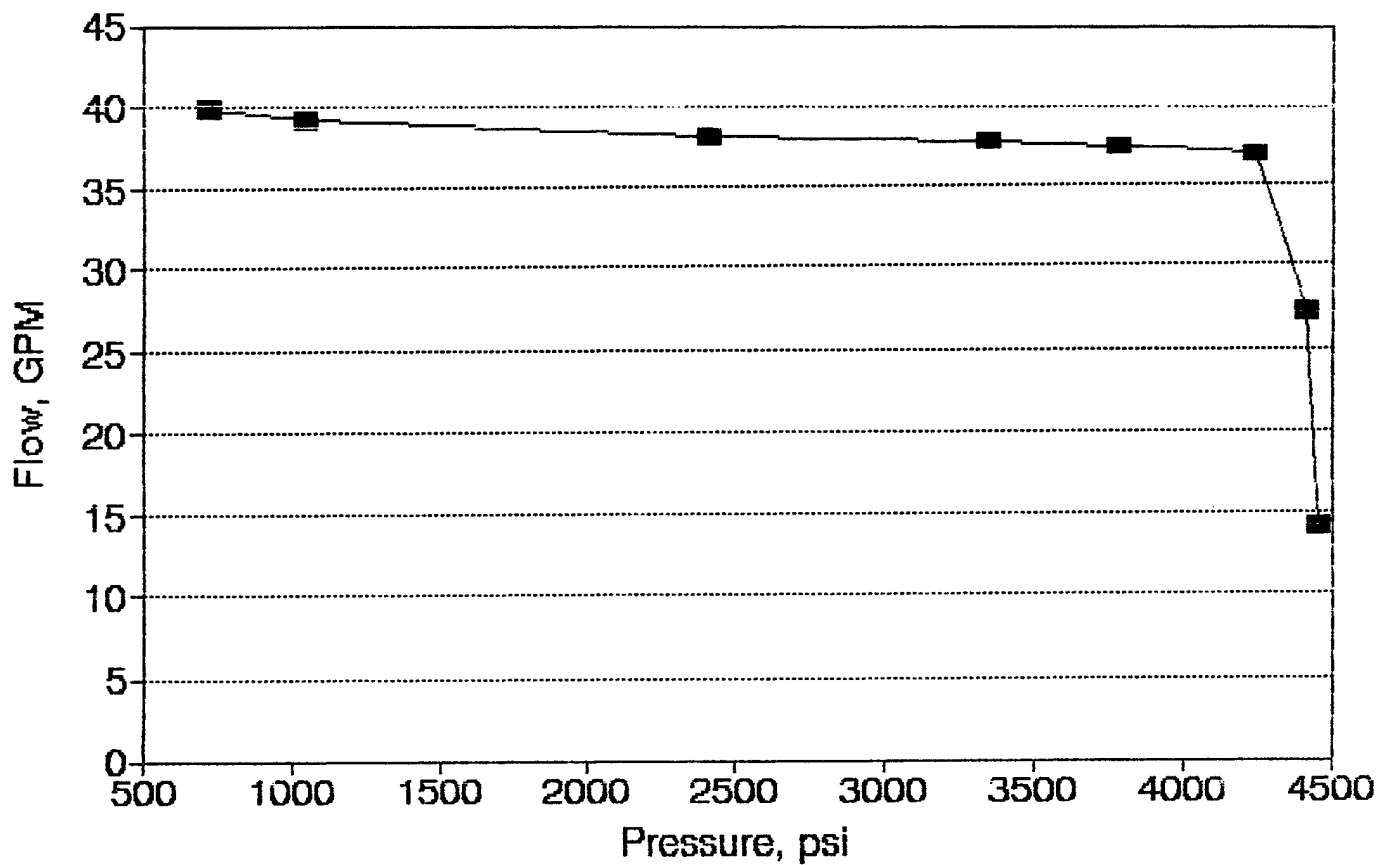


Figure B-1. Flow vs. Pressure, 1-26-94

PUMP EFF. vs. PRESSURE 1-26-94

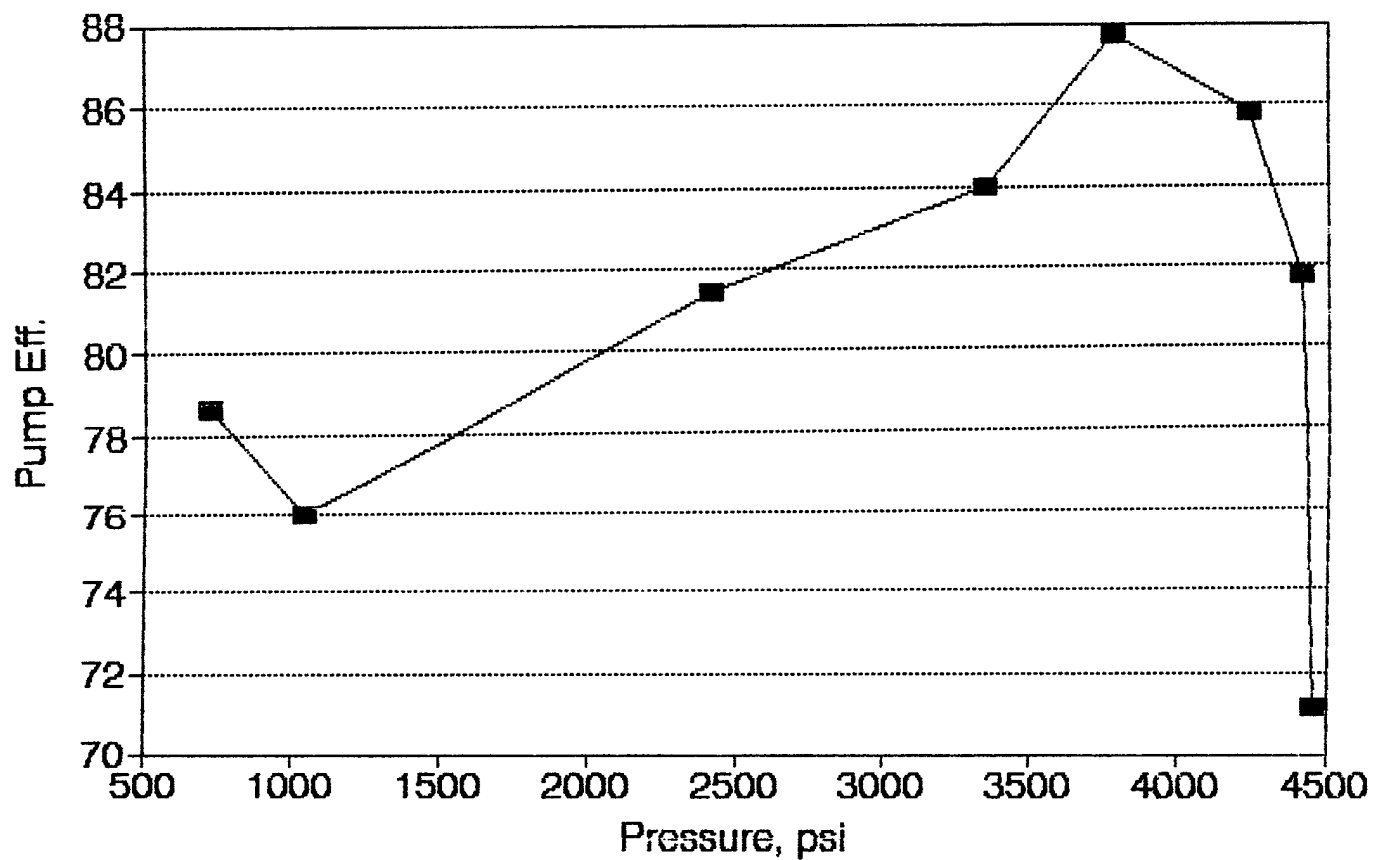


Figure B-2. Pump Efficiency vs. Pressure, 1-26-94

FLOW vs. PRESSURE 3-14-94

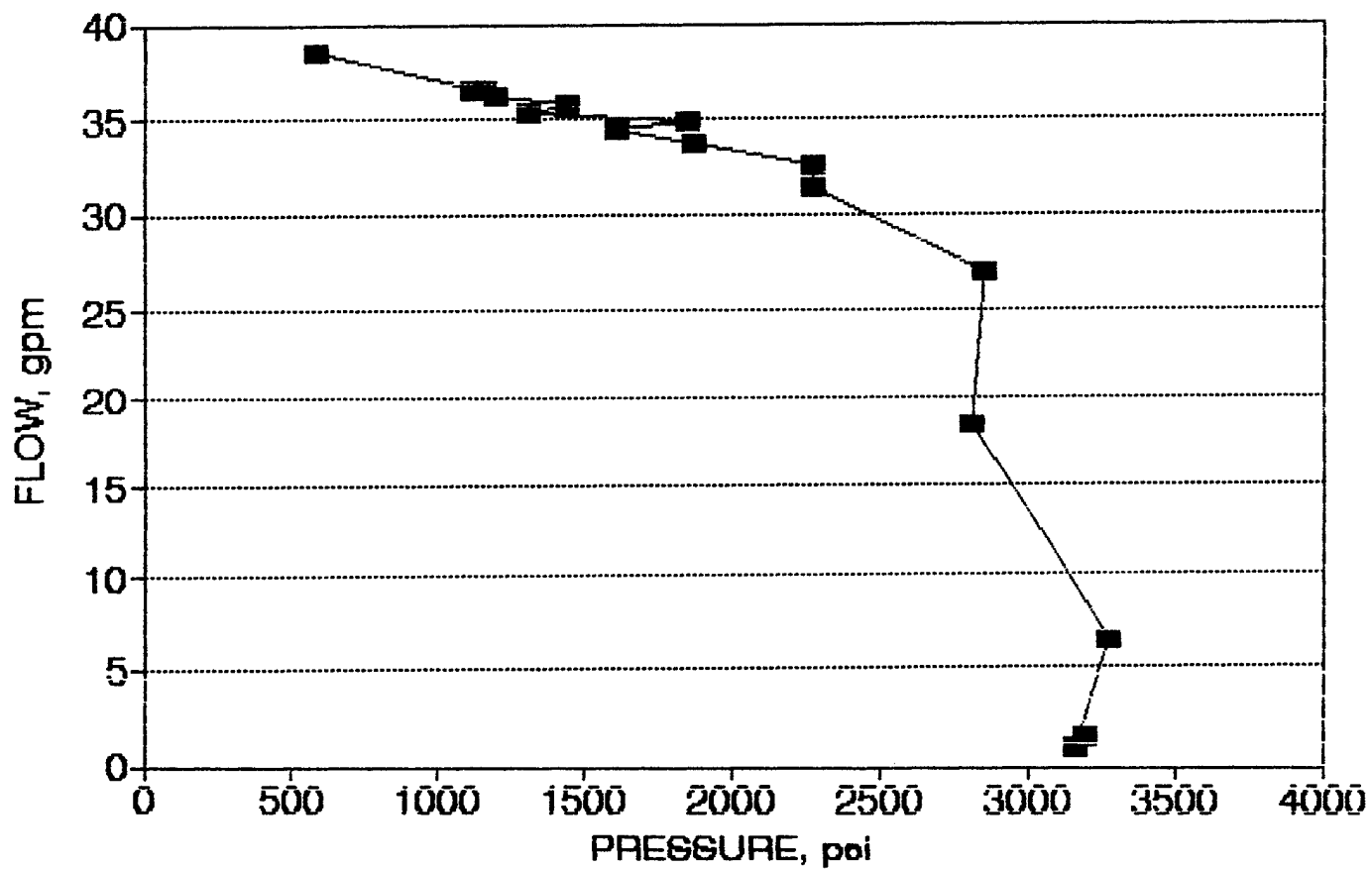


Figure B-3. Flow vs. Pressure, 3-14-94

PUMP EFF. vs. PRESSURE 3-14-94

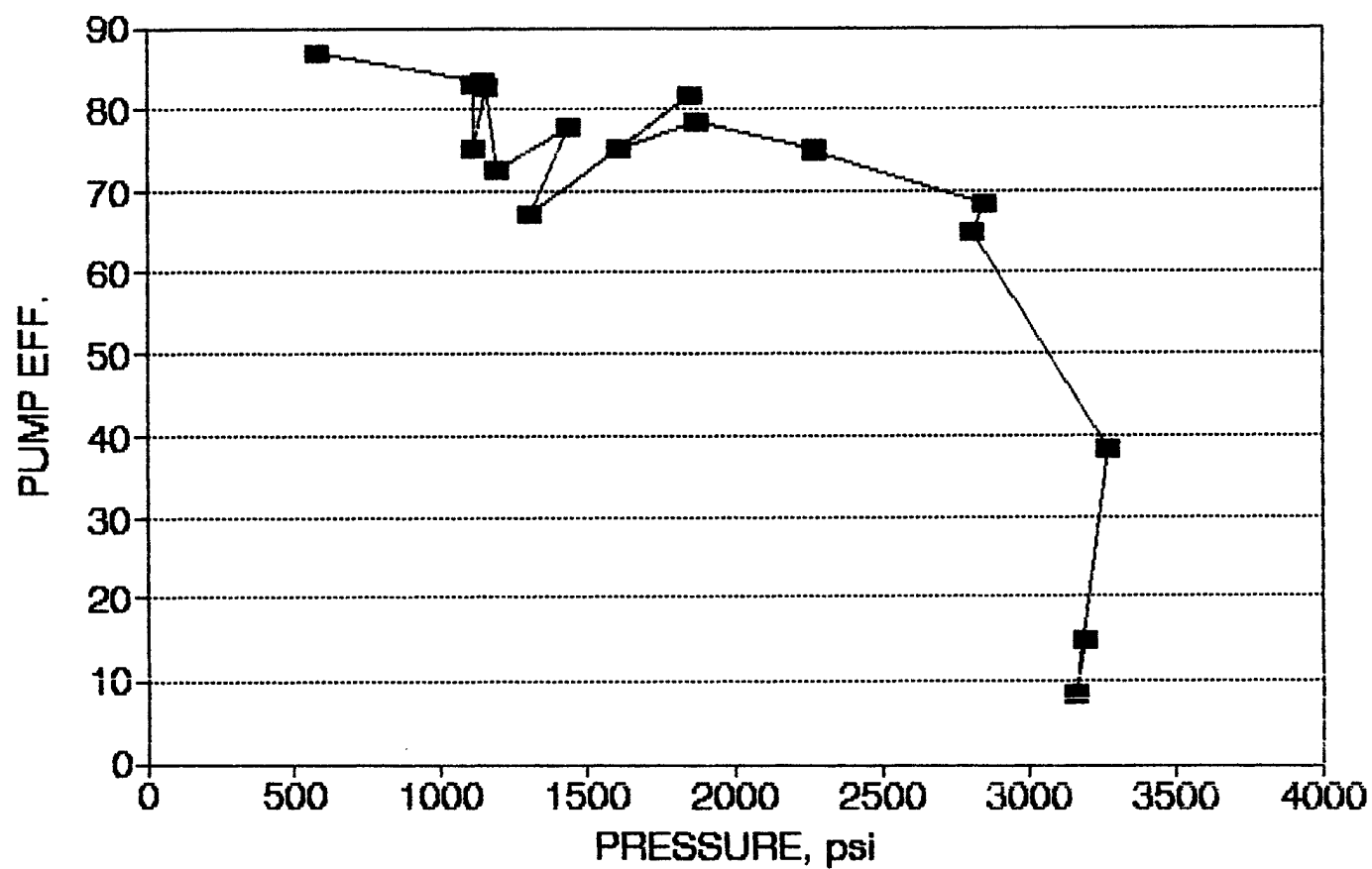


Figure B-4. Pump Efficiency vs. Pressure, 3-14-94

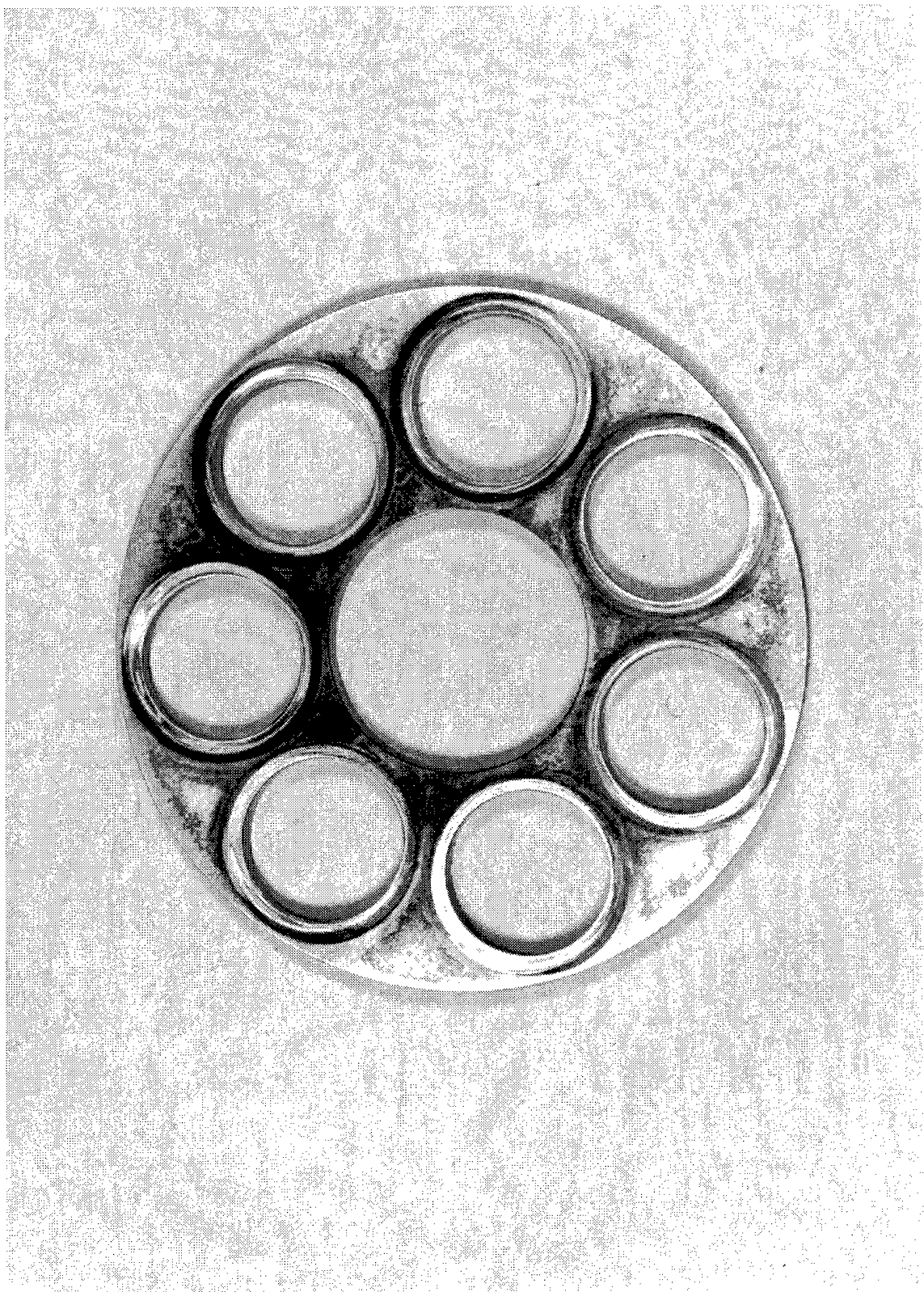
Table B-1. Fluid Laboratory Test Results

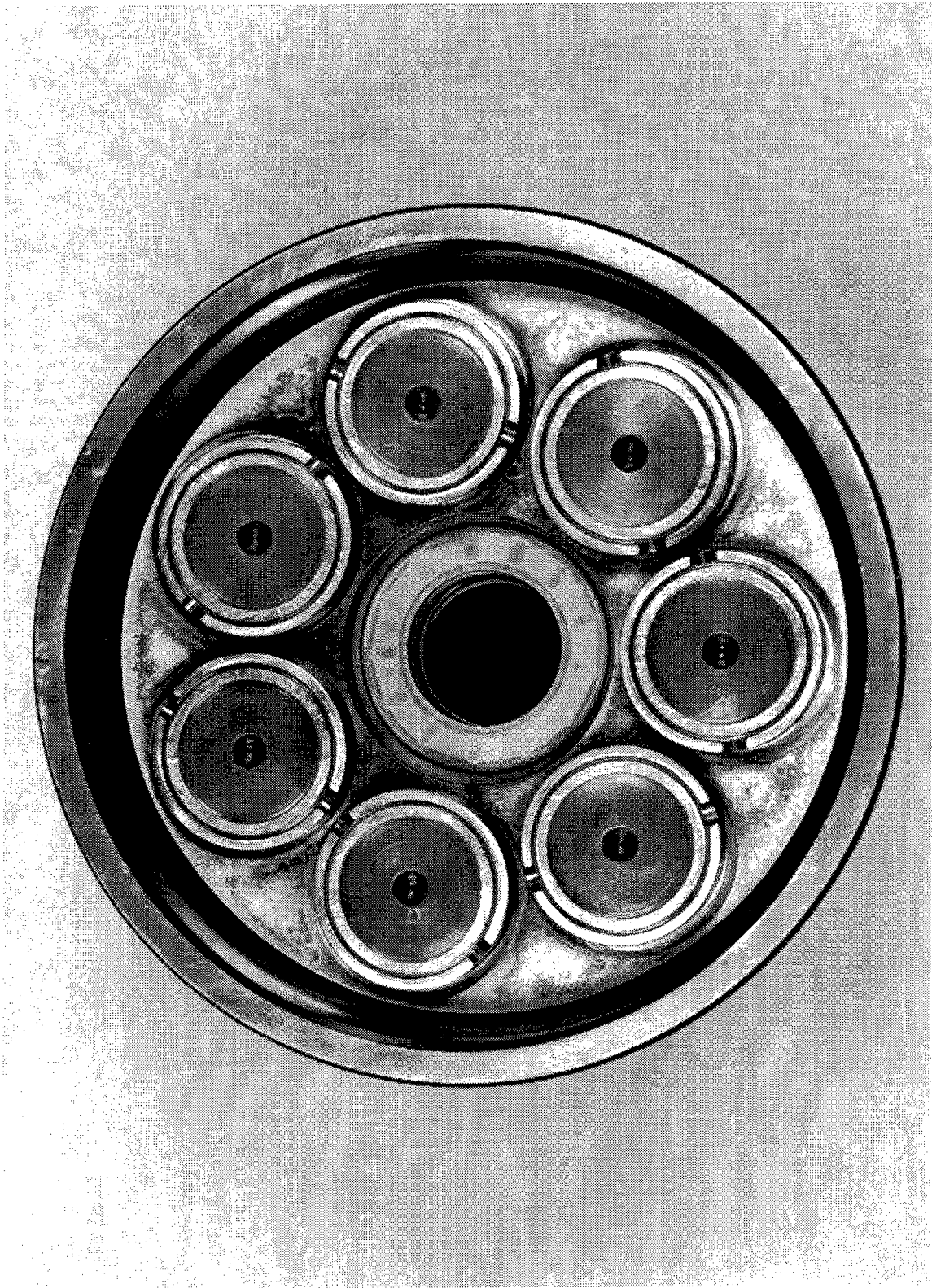
Sample Hrs.	Viscosity		Visual Appearance	Total Acid Number (TAN)* (mg KOH/g)	Metals				
	40°C (cSt)	100°C (cSt)			Zn	Fe	Cu	Sn	Al (ppm)
0	2.82	0.99	clear	0.45	24.5	2.9	1.1	6.5	2619
10	2.81	0.98	cloudy	0.41	25.8	4.0	2.0	3.4	1275
24	2.82	0.98	yellow	0.40	25.1	4.3	1.1	6.2	1338
41	2.82	0.98	gold	0.42	22.8	6.2	2.0	3.3	1093
* ASTM 664									

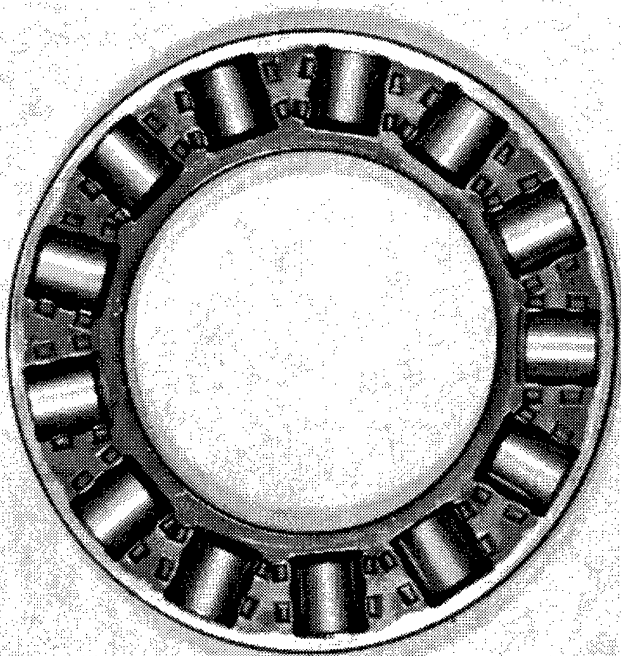


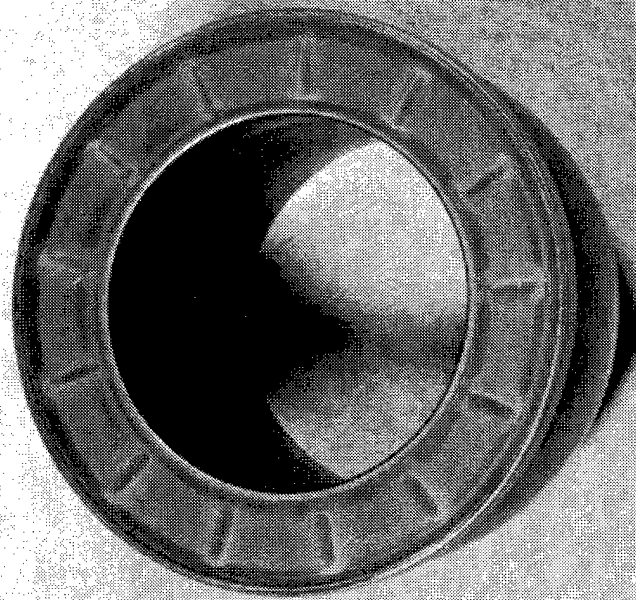
Figure B-5. Pump Discharge Filter

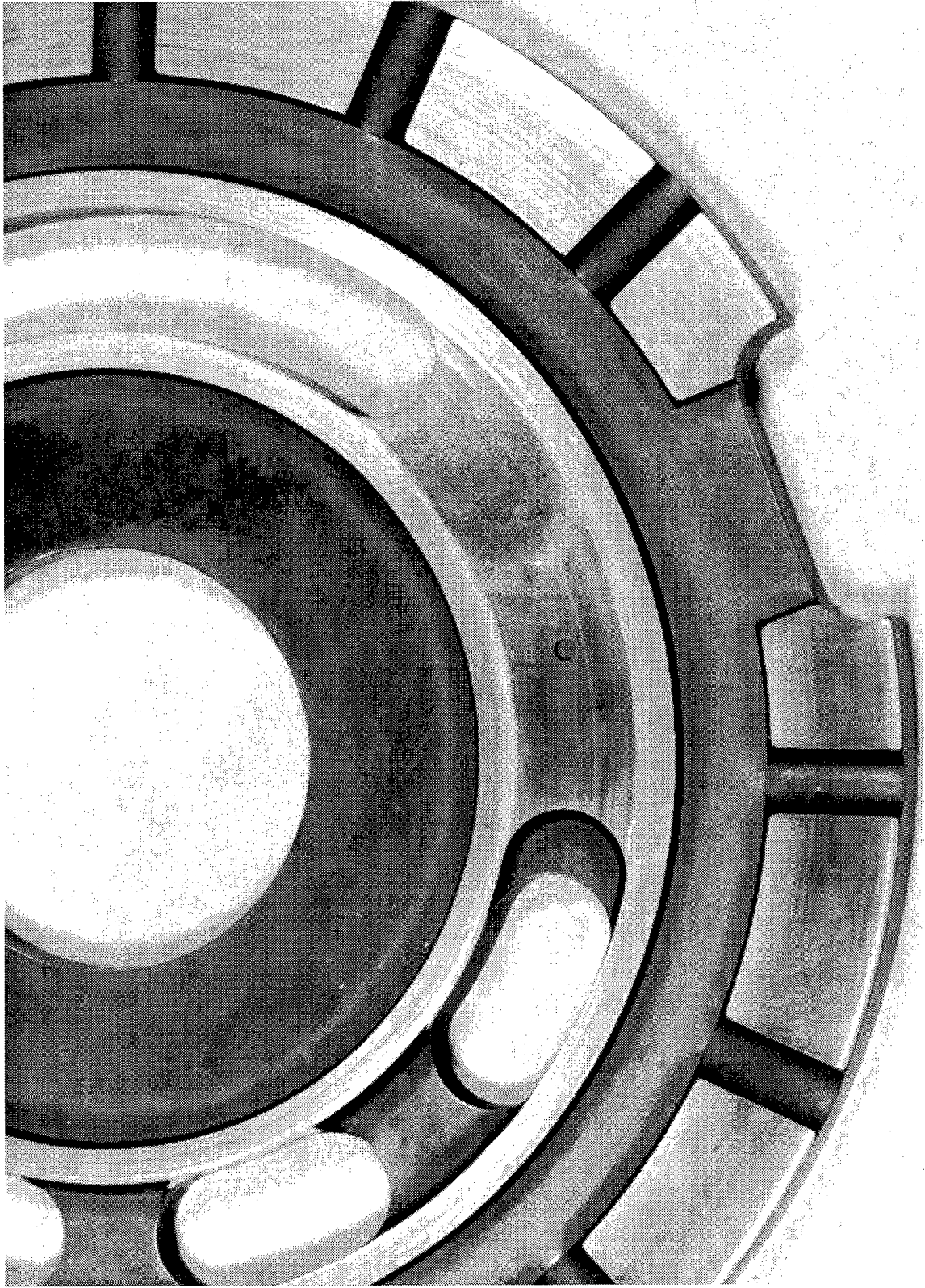
APPENDIX C
PUMP PHOTOGRAPHS

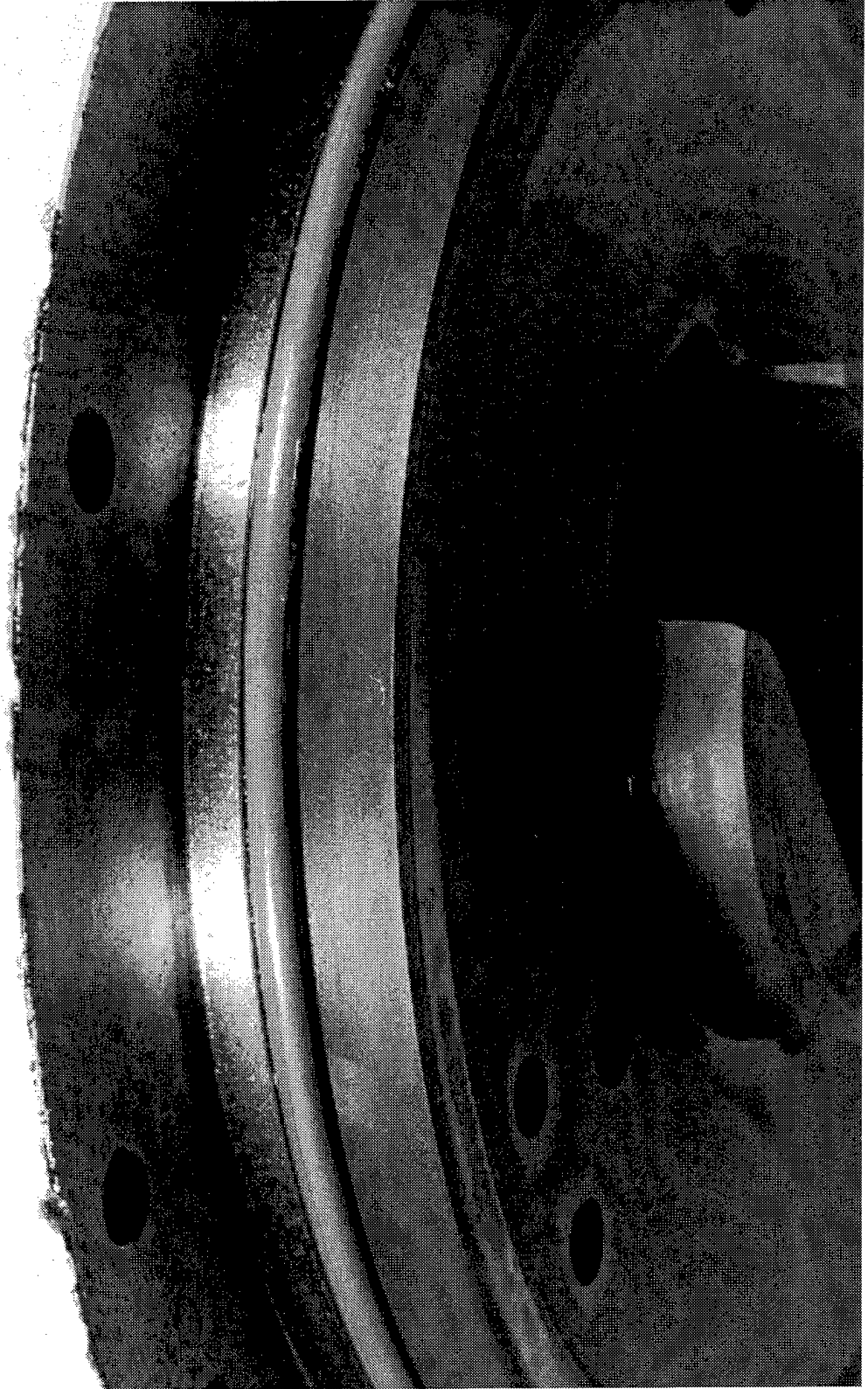


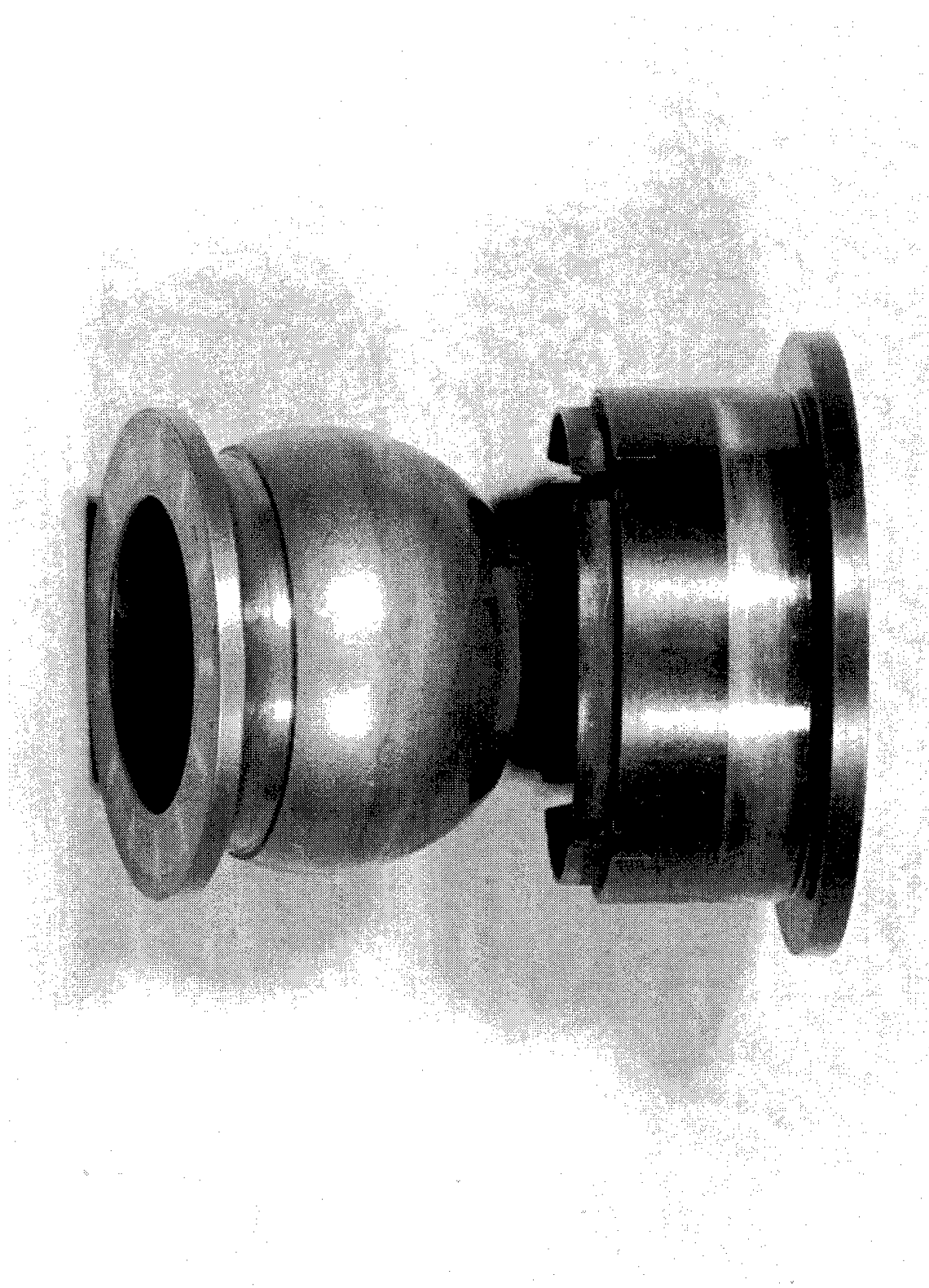


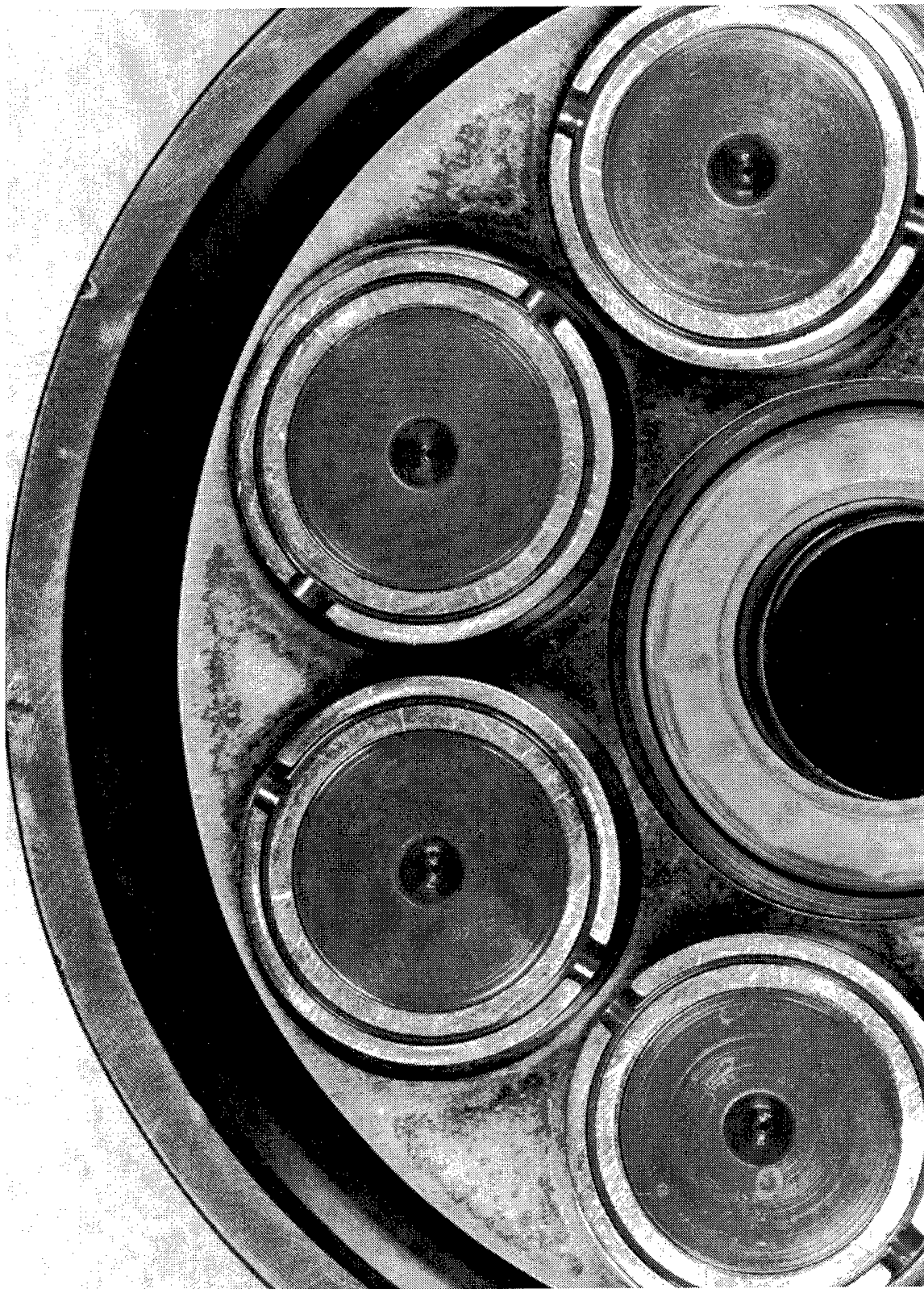


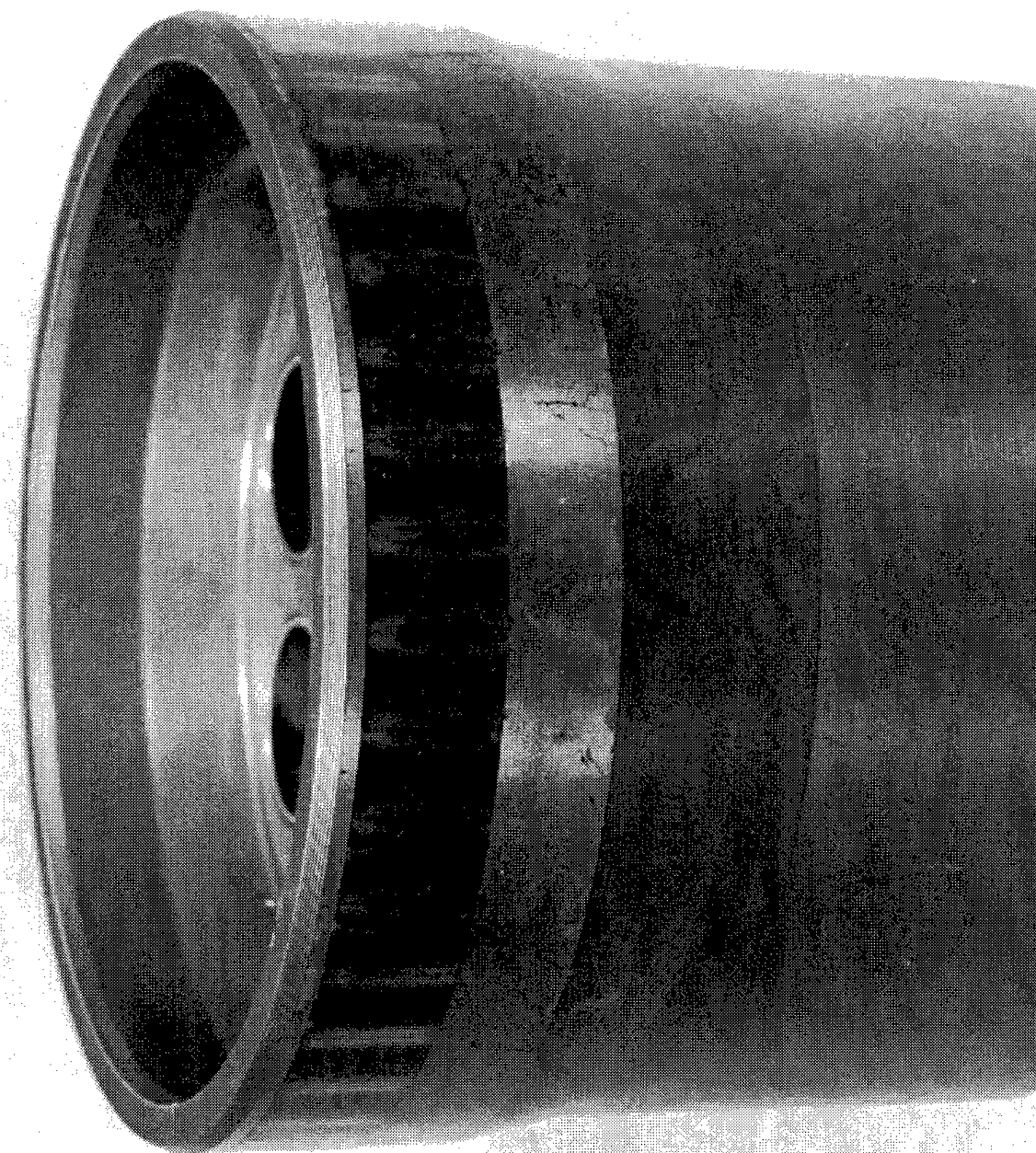


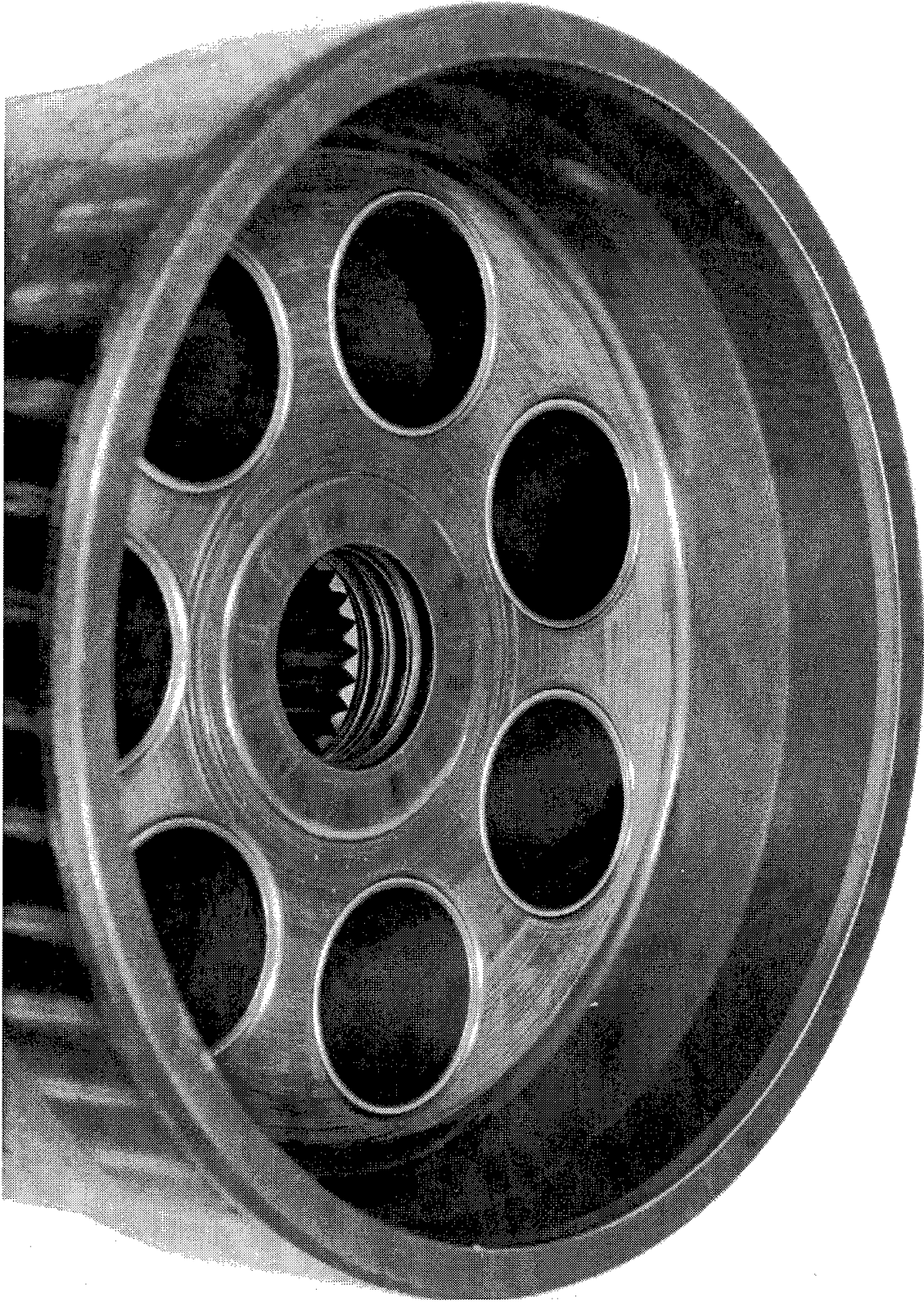




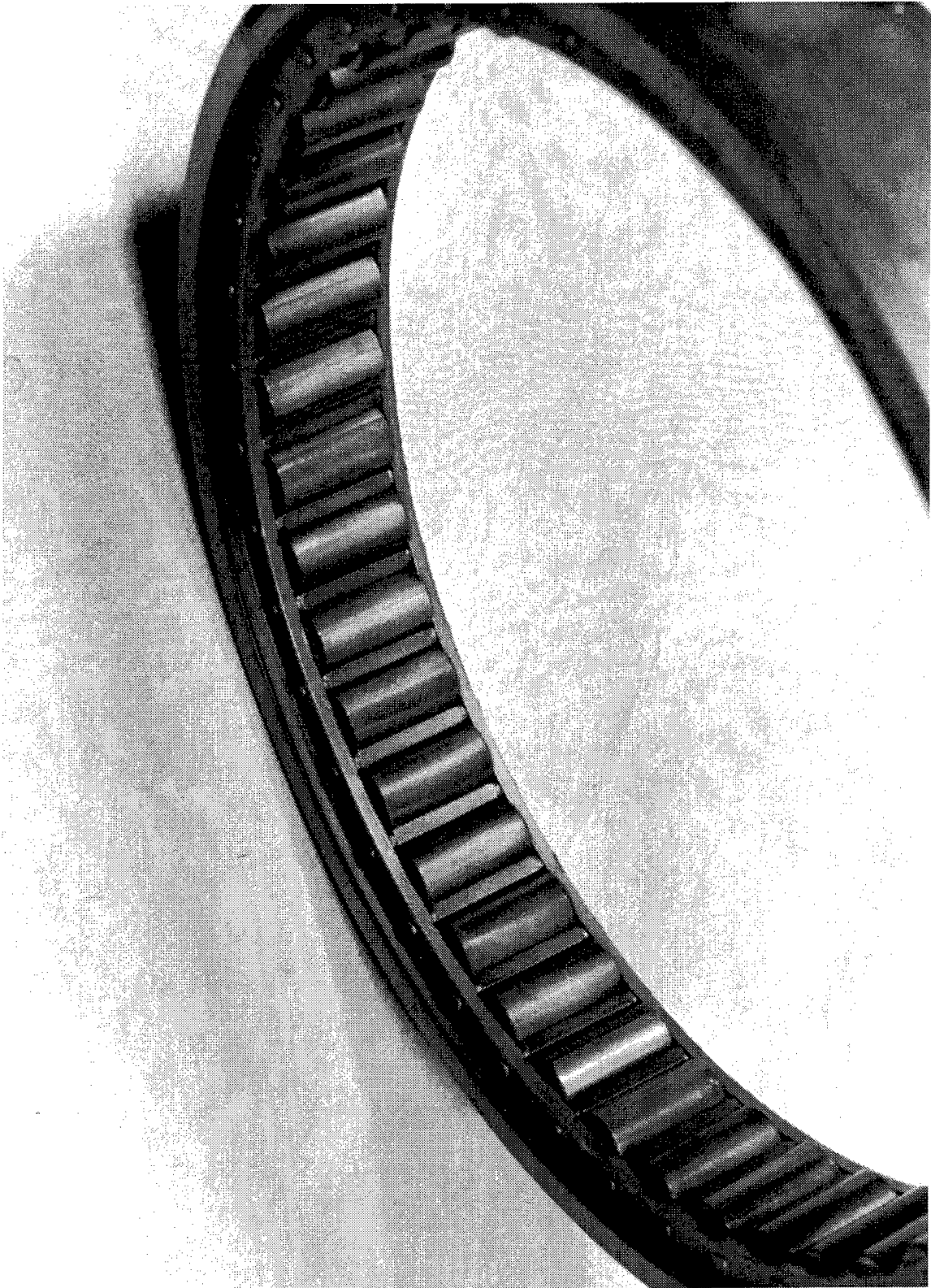


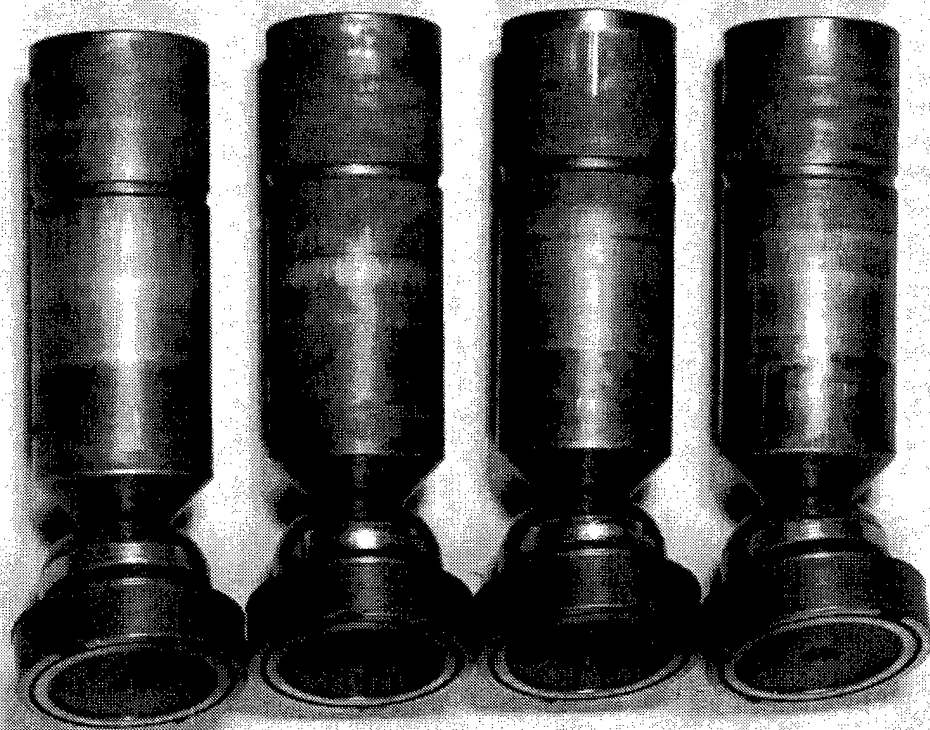


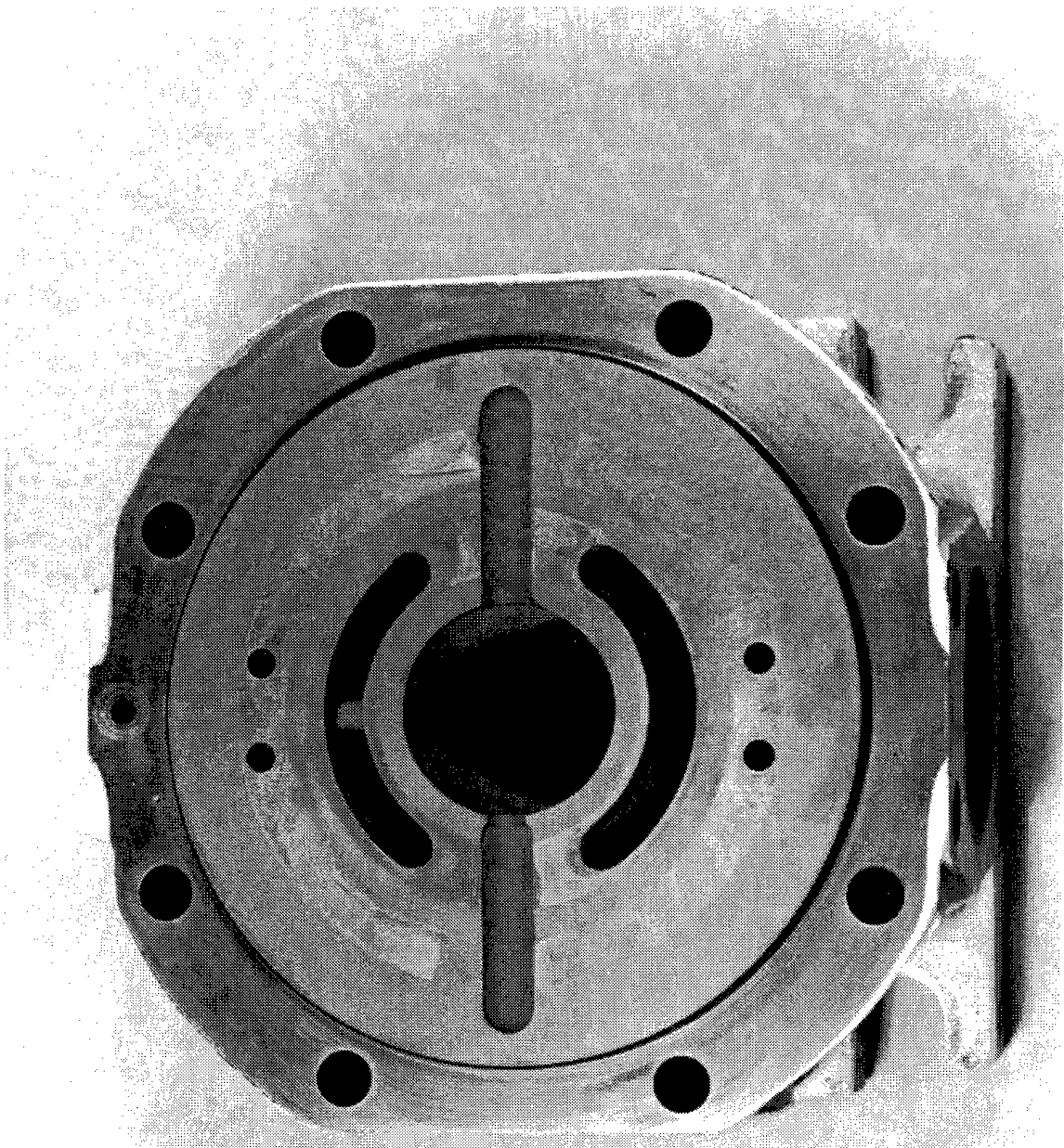


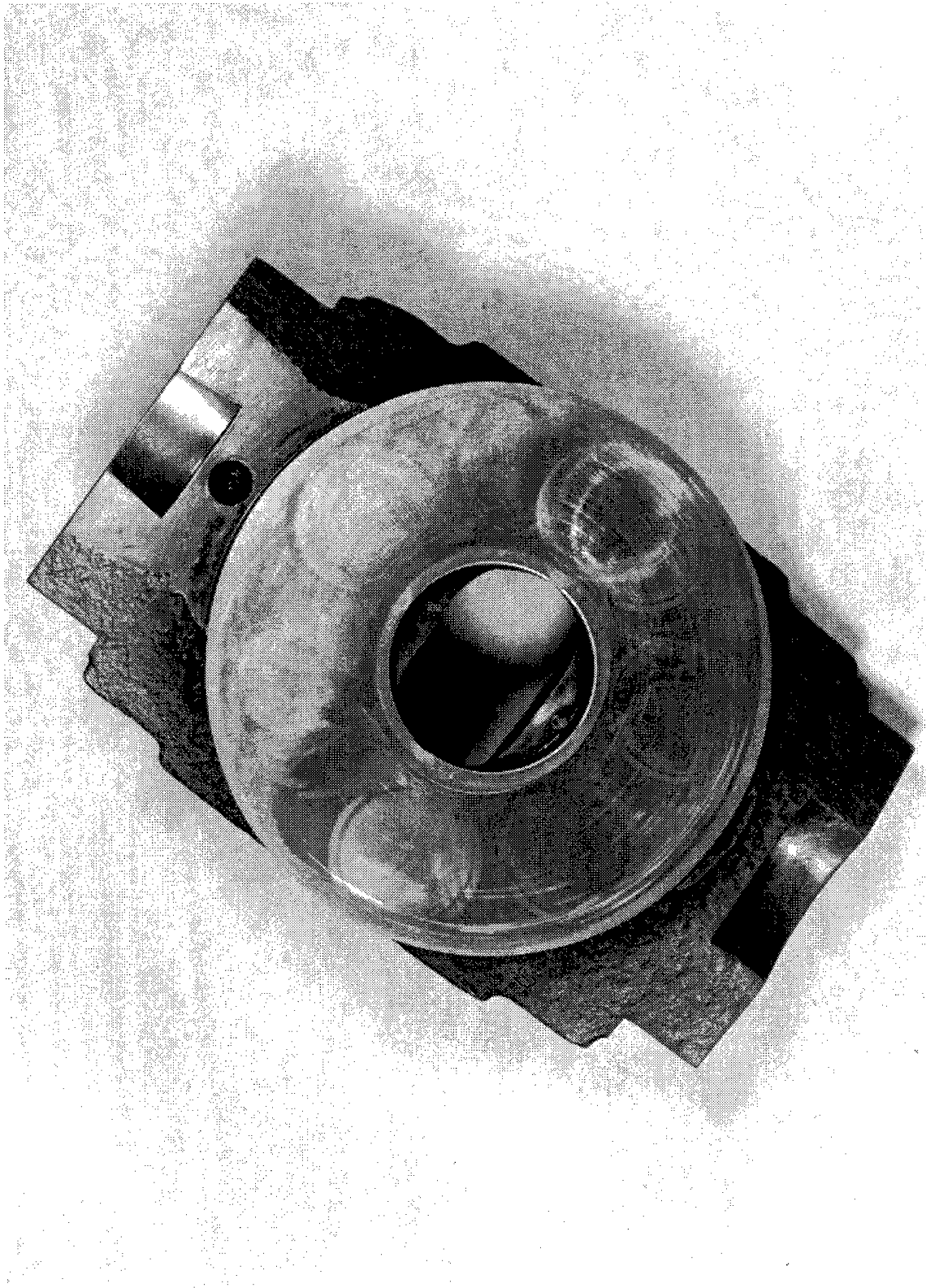


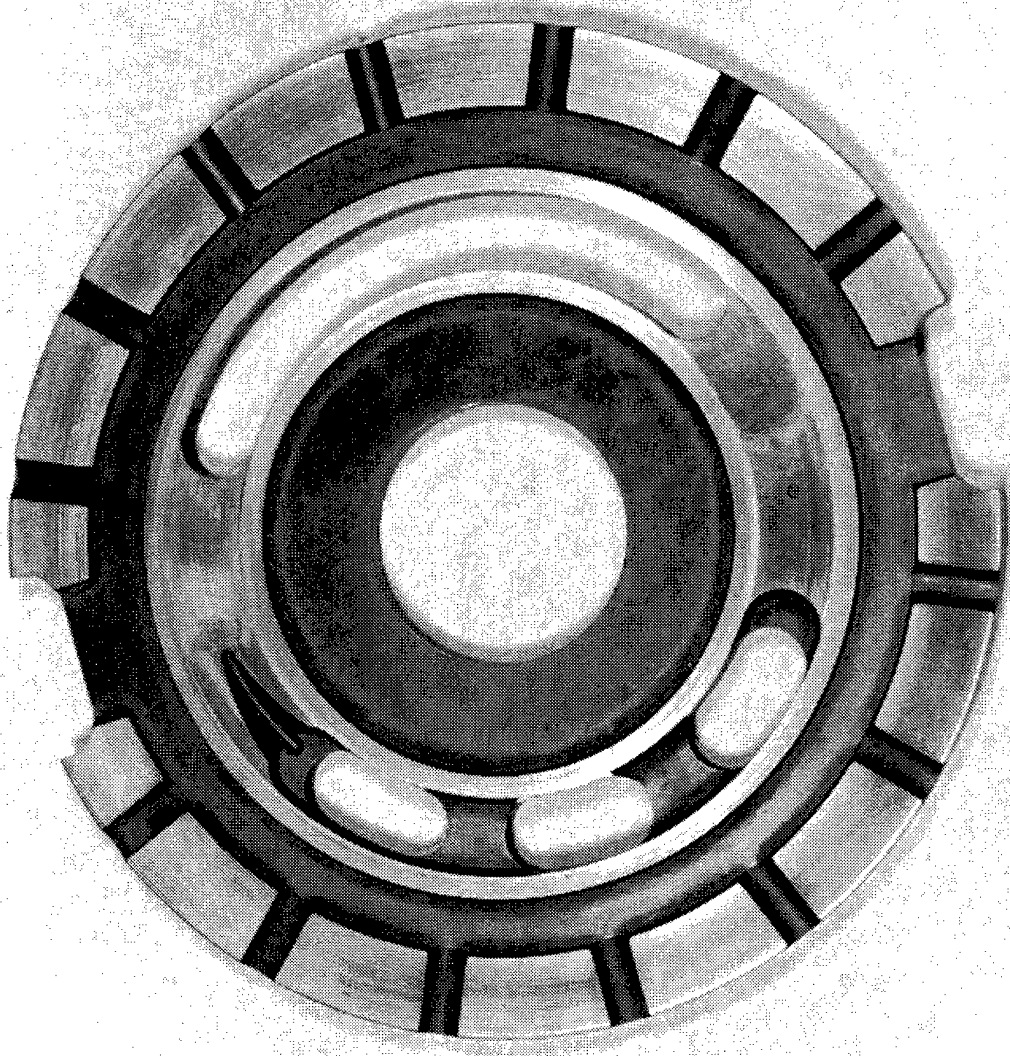


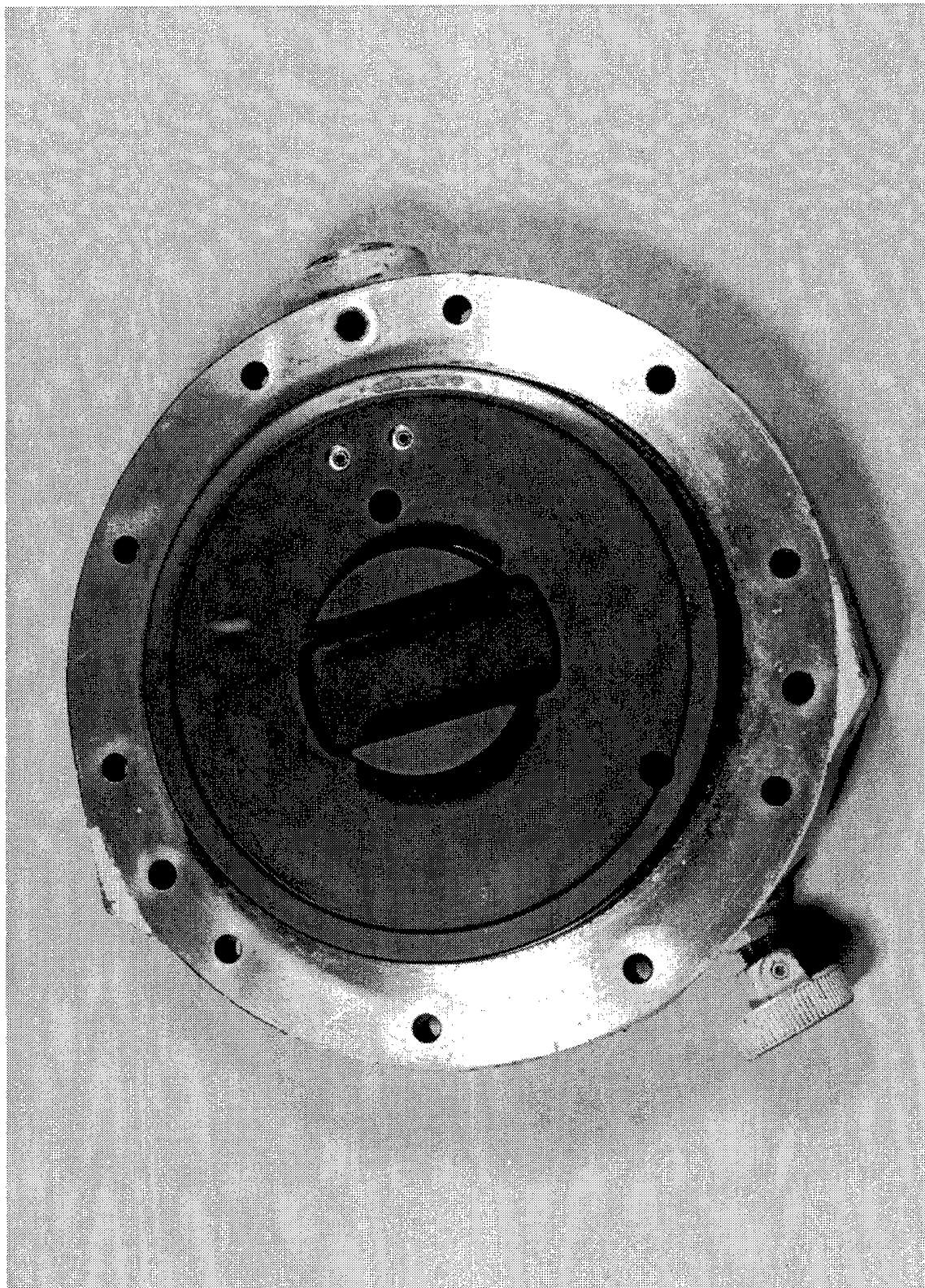














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SFAE ASM AG	1		
CDR TACOM		CDR ARMY WATERVLIET ARSN	
WARREN MI 48397-5000		ATTN: SARWY RDD	1
		WATERVLIET NY 12189	
PROG EXEC OFFICER		DIR AMC LOG SPT ACT	
ARMORED SYS MODERNIZATION		ATTN: AMXLS LA	1
ATTN: SFAE FAS AL	1	REDSTONE ARSENAL	
SFAE FAS PAL	1	AL 35890-7466	
PICATINNY ARSENAL			
NJ 07806-5000		CDR FORSCOM	
		ATTN: AFLG TRS	1
CDR APC		FT MCPHERSON GA 30330-6000	
ATTN: SATPC L	1		
SATPC Q	1	CDR TRADOC	
NEW CUMBERLAND PA 17070-5005		ATTN: ATCD SL 5	1
		INGALLS RD BLDG 163	
CDR ARMY LEA		FT MONROE VA 23651-5194	
ATTN: LOEA PL	1		
NEW CUMBERLAND PA 17070-5007		CDR ARMY ARMOR CTR	
		ATTN: ATSB CD ML	1
		ATSB TSM T	1
		FT KNOX KY 40121-5000	

CDR ARMY TECOM		CDR ARMY QM SCHOOL	
ATTN: AMSTE TA R	1	ATTN: ATSM PWD	1
AMSTE TC D	1	FT LEE VA 23001-5000	
AMSTE EQ	1		
APG MD 21005-5006		CDR ARMY FIELD ARTY SCH	
		ATTN: ATSF CD 1	
PROJ MGR MOBILE ELEC PWR		FT SILL OK 73503	
ATTN: AMCPM MEP T	1		
AMCPM MEP L	1	CDR ARMY TRANS SCHOOL	
7798 CISSNA RD STE 200		ATTN: ATSP CD MS	1
SPRINGFIELD VA 22150-3199		FT EUSTIS VA 23604-5000	
CDR		CDR ARMY INF SCHOOL	
ARMY COLD REGION TEST CTR		ATTN: ATSH CD 1	
ATTN: STECR TM	1	ATSH AT	1
STECR LG	1	FT BENNING GA 31905-5000	
APO AP 96508-7850			
		CDR ARMY ABERDEEN TEST CTR	
CDR		ATTN: STEAC EN	1
ARMY BIOMED RSCH DEV LAB		STEAC LI	1
ATTN: SGRD UBZ A	1	STEAC AE	1
FT DETRICK MD 21702-5010		STEAC AA	1
		APG MD 21005-5059	
CDR ARMY AVIA CTR			
ATTN: ATZQ DOL M	1	CDR ARMY YPG	
FT RUCKER AL 36362-5115		ATTN: STEYP MT TL M	1
		YUMA AZ 85365-9130	
CDR ARMY ENGR SCHOOL			
ATTN: ATSE CD	1	CDR ARMY CERL	
FT LEONARD WOOD		ATTN: CECER EN	1
MO 65473-5000		P O BOX 9005	
		CHAMPAIGN IL 61826-9005	
CDR 49TH QM GROUP			
ATTN: AFFL GC	1	DIR 1	
FT LEE VA 23801-5119		AMC FAST PROGRAM	
		10101 GRIDLEY RD STE 104	
CDR ARMY ORDN CTR		FT BELVOIR VA 22060-5818	
ATTN: ATSL CD CS	1		
APG MD 21005		CDR I CORPS AND FT LEWIS	
		ATTN: AFZH CSS	1
		FT LEWIS WA 98433-5000	
CDR			
RED RIVER ARMY DEPOT		CDR 6TH ID (L)	
ATTN: SDSRR M	1	ATTN: APUR LG M	1
SDSRR Q	1	1060 GAFFNEY RD	
TEXARKANA TX 75501-5000		FT WAINWRIGHT AK 99703	
PS MAGAZINE DIV		CDR ARMY SAFETY CTR	
ATTN: AMXLS PS	1	ATTN: CSSC PMG	1
DIR LOGSA		CSSC SPS	1
REDSTONE ARSENAL		FT RUCKER AL 36362-5363	
AL 35898-7466			

Department of the Navy

OFC CHIEF NAVAL OPER ATTN: DR A ROBERTS (N420) 2000 NAVY PENTAGON WASHINGTON DC 20350-2000	1	CDR NAVAL AIR WARFARE CTR ATTN: CODE PE33 AJD P O BOX 7176 TRENTON NJ 08628-0176	1
CDR NAVAL SEA SYSTEMS CMD ATTN: SEA 03M3 2531 JEFFERSON DAVIS HWY ARLINGTON VA 22242-5160	1	CDR 1 NAVAL PETROLEUM OFFICE 8725 JOHN J KINGMAN RD STE 3719 FT BELVOIR VA 22060-6224	
CDR NAVAL SURFACE WARFARE CTR ATTN: CODE 63	1	CDR	
CODE 632	1	NAVAL RSCH LABORATORY	
CODE 859	1	ATTN: CODE 6181	1
3A LEGGETT CIRCLE ANNAPOLIS MD 21402-5067		WASHINGTON DC 20375-5342	

Department of Navy/U.S. Marine Corps

HQ USMC ATTN: LPP WASHINGTON DC 20380-0001	1	CDR BLOUNT ISLAND CMD ATTN: CODE 922/1 5880 CHANNEL VIEW BLVD JACKSONVILLE FL 32226-3404	1
PROG MGR COMBAT SER SPT MARINE CORPS SYS CMD 2033 BARNETT AVE STE 315 QUANTICO VA 22134-5080	1	CDR MARINE CORPS LOGISTICS BA ATTN: CODE 837 814 RADFORD BLVD ALBANY GA 31704-1128	1
PROG MGR GROUND WEAPONS MARINE CORPS SYS CMD 2033 BARNETT AVE QUANTICO VA 22134-5080	1	CDR 1 2ND MARINE DIV PSC BOX 20090 CAMP LEJEUNE NC 28542-0090	
PROG MGR ENGR SYS MARINE CORPS SYS CMD 2033 BARNETT AVE QUANTICO VA 22134-5080	1	CDR 1 FMFPAC G4 BOX 64118 CAMP H M SMITH HI 96861-4118	
CDR MARINE CORPS SYS CMD ATTN: SSE 2030 BARNETT AVE STE 315 QUANTICO VA 22134-5010	1		

Department of the Air Force

HQ USAF/LGTV ATTN: VEH EQUIP/FACILITY 1030 AIR FORCE PENTAGON WASHINGTON DC 20330-1030	1	SA ALC/SFT 1014 BILLY MITCHELL BLVD STE 1 KELLY AFB TX 78241-5603	1
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AIR FORCE WRIGHT LAB ATTN: WL/POS1 WL/POSL 1790 LOOP RD N WRIGHT PATTERSON AFB OH 45433-7103	1	SA ALC/LDPG ATTN: D ELLIOTT 580 PERRIN BLDG 329 KELLY AFB TX 78241-6439	1
AIR FORCE WRIGHT LAB ATTN: WL/MLBT 2941 P ST STE 1 WRIGHT PATTERSON AFB OH 45433-7750	1	WR ALC/LVRS 225 OCMULGEE CT ROBINS AFB GA 31098-1647	1
AIR FORCE WRIGHT LAB ATTN: WL/MLSE 2179 12TH ST STE 1 WRIGHT PATTERSON AFB OH 45433-7718	1	AIR FORCE MEEP MGMT OFC OL ZC AFMC LSO/LOT PM 201 BISCAYNE DR BLDG 613 STE 2 ENGLIN AFB FL 32542-5303	1

Other Federal Agencies

NASA LEWIS RESEARCH CENTER CLEVELAND OH 44135	1	EPA AIR POLLUTION CONTROL 2565 PLYMOUTH RD ANN ARBOR MI 48105	1
RAYMOND P. ANDERSON, PH.D., MANAGER FUELS & ENGINE TESTING BDM-OKLAHOMA, INC. 220 N. VIRGINIA BARTLESVILLE OK 74003	1	DOT FAA AWS 110 800 INDEPENDENCE AVE SW WASHINGTON DC 20590	1